AD-A190 241

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): NATICK/TR-88/002	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: U.S. Army Natick R,D&E Center; 6b. OFFICE SYMBOL (If applicable): STRNC-ICAS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Natick, MA 01760-5019	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: U.S. Army Aviation Systems Command; 8b. OFFICE SYMBOL (If applicable): AMCPM-ALSE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): 3500 Goodfellow Blvd. St. Louis, MO 63120-1798	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 694000; PROJECT NO. 16; TASK NO.; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
(U) THE EFFECTS OF DIFFERENT COMBINATIONS OF INLET AIR CONDITIONS USED FOR COOLING AS MEASURED ON A HEATED MANIKIN

12. PERSONAL AUTHOR(S)
Barry S. DeCristofano and Joseph S. Cohen

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Dec 86 TO Jan 87	October 1987	31

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	AIR CONDITIONING EQUIPMENT	VESTS	AIR COOLING
			MICROCLIMATE COOLING	SWEATING SKIN	DEW POINT
			PROTECTIVE CLOTHING	MANIKINS	FLOW RATE

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The effects of using different inlet air conditions on the cooling performance of the Army's microclimate air vest were studied. A significant difference was found between the use of a 75°F dew point, and either a 60, 65, or 70°F dew point. The interaction between dew point and flow rate was also found to be significant. The testing was done on a sectionalized heated manikin featuring a "sweating skin". The results may provide some preliminary guidlines for the development of microclimate cooling equipment. The findings also suggest courses of investigation that future studies should be directed towards. Keywords: mannequins, sweat cooling, protective clothing

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Barry S. DeCristofano	22b. TELEPHONE (Include Area Code): (617) 651-5439; 22c. OFFICE SYMBOL: STRNC-ICAS

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

BLANK

PREFACE

The testing described in this report was conducted to better define the operational parameters associated with air microclimate cooling. Measurements of the power required for a heated manikin to maintain a set surface temperature were made while the conditions of the cooling air were varied.

Data of this nature benefits those involved in both the design of cooling garments and the design of the equipment used to provide the cooling.

The research was carried out with funding provided by the U.S. Army Aviation Systems Command, PRON EJ6-ET094-01-EJPG, dated 9Dec86; Natick R,D&E Center (NRDEC) Program Element No. 694000. The work was conducted on the heated manikin owned by the U.S. Navy Clothing and Textile Research Facility (NCTRF), Natick, MA 01760, MIPR Natick 87-190.

The authors wish to acknowledge Mr. Joseph Giblo (NCTRF) and Mr. Bruce Rosen (NRDEC) for their assistance in this project.

BLANK

TABLE OF CONTENTS

BLANK

LIST OF FIGURES

LIST OF TABLES

THE EFFECTS OF DIFFERENT COMBINATIONS OF INLET AIR CONDITIONS USED FOR COOLING AS MEASURED ON A HEATED MANIKIN

INTRODUCTION

The requirement for microclimate cooling for soldiers wearing chemical-biological protective gear has been documented in many reports in the last decade (Ref. 1,2). On the basis of these studies, cooling systems are now finding their way into the field. Designing portable or vehicle mounted microclimate units involves a trade-off between power/mass/volume constraints and cooling requirements. The former are fixed by the vehicle type and the mission scenarios. The latter are governed by the operational environment, work cycles and crew size.

To assist the equipment designer, information regarding the capabilities and limitations of the mode of cooling (air or liquid) and of the garments being used must be made available. Static measurements on a heated manikin, though not fully representative of a man in the field can provide some baseline data around which system calculations can be made. To this end, a series of trials were conducted on a "sweating", heated manikin. Air cooling was the mode investigated using combinations of dry bulb temperature, dew point and flow rate of the inlet air.

The effort was funded by U.S. Army Aviation Systems Command (AVSCOM). The tests were run at the Navy Clothing and Textile Research Facility (NCTRF) in Natick, Massachusetts from December 1986 through January 1987.

EXPERIMENTAL METHOD

The heated manikin was divided into ten separate regions - torso, arms (2), legs (2), feet (2), hands (2), and head. The torso had a maximum power input of 1,840 $Btu \cdot hr^{-1}$ (540 W) (1 W = 1 $J \cdot sec^{-1}$), the arms and head had limits of 307 $Btu \cdot hr^{-1}$ (90 W). The surface of the manikin was maintained at 95°F (35°C).

The manikin was covered with a "sweating skin" consisting of capillary tubing sewn into a cotton suit covering the entire manikin. The tubing was configured into six parallel circuits defining six body regions: head, torso, right and left arms, and right and left legs. The flow of water into each region was independent of the other five regions.

Six metering pumps allow for this control. The total flow rate was 0.32 $gal \cdot hr^{-1}$ ($1.2x10^{-3}$ $m^3 \cdot hr^{-1}$). This value was representative of sweat rates measured during air microclimate tests with human subjects (Ref. 3). Water was distributed as follows: fifty percent to the torso, twenty-five percent to the legs, fifteen percent to the arms and ten percent to the head. Again, these numbers reflect the approximate distribution in humans. The temperature of the water was kept at 95°F (35°C).

The clothing ensemble consisted of the air vest, the Aircrew Uniform, Integrated Battlefield (AUIB), the M43 face mask, the Aircrew Integrated Helmet System (AIHS), or HGU56, and the aircrew body armor. Butyl rubber gloves and boots were also worn. The air vest (Fig. 1) distributed air over the torso to the chest, neck, and back in a 7:3:10 ratio. The M43 mask (Fig. 2) was designed to divert a portion of the air supplied to the nosecup up and over the top of the head.

The air delivery unit was mounted on wheels and drew air from the test chamber, cooled the air to the desired dew point, and then reheated the air to the required dry bulb temperature. Flow rate was controlled by a ball valve downstream of the conditioning unit.

Thirty-two sets of inlet air conditions were used. Four dew points - 60, 65, 70, and 75°F (16, 18, 21, and 24°C); two dry bulb temperatures - 80 and 90°F (27 and 32 C); lastly four flow rates - 15, 12, 9, and 4 $ft^3 \cdot min^{-1}$ (cfm) (0.42, 0.34, 0.25, and 0.11 $m^3 \cdot min^{-1}$) (Fig. 3). Air was directed only to the head during the 4 cfm conditions, simulating the use of the blower unit designed for the M43 facepiece. The higher flow rates were split by a Y-connector, sending 3 cfm (0.08 $m^3 \cdot min^{-1}$) to the head and the remainder to the torso via the air vest. Environmental conditions in the test chamber were set to provide a wet bulb globe temperature (WBGT) of 105°F (40.6°C) representing conditions in a helicopter cockpit (Appendix A). Inlet air dry bulb temperature was measured by placing a Type T thermocouple at the entrance to the Y-connector. At the same location, an air sample was drawn to obtain a dew point reading on a General Eastern Model 1100 chilled-mirror hygrometer. In an attempt to determine the dew point of the air exiting the ensemble, a sample was also drawn from an opening in the AUIB at the side of the torso.

Each test run was terminated when the power level supplied to the torso region of the manikin had leveled off for a period of at least one hour after the inlet air conditions were changed.

After collection of the data, a multifactor analysis of variance (ANOVA) and Duncan's multiple range test were performed to determine any significant effects between the main factors and any interactions of the main factors.

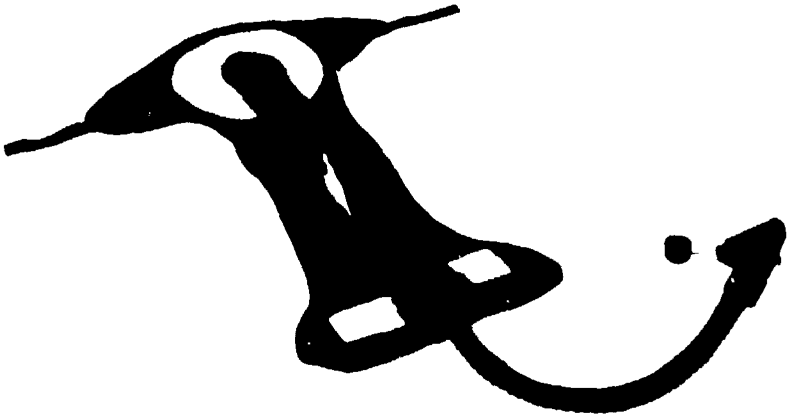

Figure 1. The microclimate air vest.

Figure 2. The M43 facemask.

	60		65		70		75	
80	1 15 1/23 31	2 12 12/9 1	5 15 1/22 30	6 12 12/16 9	9 15 1/21 25	10 12 12/18 18	13 15 1/22 29	14 12 12/18 19
	3 9 12/9 2	4 4 12/9 3	7 9 12/16 8	8 4 12/16 7	11 9 12/18 17	12 4 12/18 16	15 9 12/18 20	16 4 12/19 21
90	17 15 1/23 32	18 12 12/12 4	21 15 1/22 28	22 12 12/16 10	25 15 1/21 26	26 12 12/17 15	29 15 1/21 27	30 12 12/19 24
	19 9 12/12 5	20 4 12/12 6	23 9 12/17 11	24 4 12/17 12	27 9 12/17 14	28 4 12/17 13	31 9 12/19 23	32 4 12/19 22

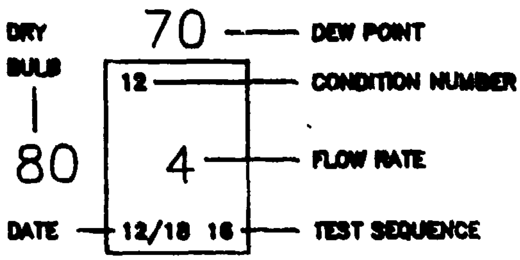

Figure 3. Thermal manikin study – test matrix.

RESULTS

In thirty-one of the thirty-two sets of experimental conditions, the only manikin regions requiring an input of power, i.e. those that received cooling, were the torso, head, and arms. For one set of conditions, 60/90/15*, a small amount of cooling was also recorded in the legs. The cooling values for all the test runs are presented in Figs. 4-7. Among the eight air conditions the values fall in line with the relative cooling potentials (Appendix B). Within each dew point/dry bulb combination, the 15 cfm cooling values did not all exceed the 12 cfm levels as would be expected.

Statistical analysis:

	65	60	70	75
Dew Point (DP) means -	113.0	112.8	104.3	81.4

	80	90
Dry Bulb (DB) means -	113.5	92.3

	12	9	15
Flow Rate (FR) means -	112.9	101.5	94.3

analysis of variance -

Source	degrees of freedom	mean square	F value	standard error
Between DPs	3	1333.5	12.4**	6.0
Between DBs	1	2690.3	25.0**	10.4
Between FRs	2	700.4	6.5***	7.3
Error	6	107.4		

The standard errors multiplied by the significant Studentized ranges for each sample size, yield the shortest significant range, Rp, by which the differences between the means are judged.

For DP -	p:	2	3	4
	Rp:	20.8	21.5	21.8
For DB -	p:	2		
	Rp:	36.0		
For FR -	p:	2	3	
	Rp:	25.3	26.1	

* test conditions will be referred to in this format - dew point/dry bulb temperature/flow rate - for each set of air conditions

** F value at 99% confidence level; *** F value at 95% confidence level

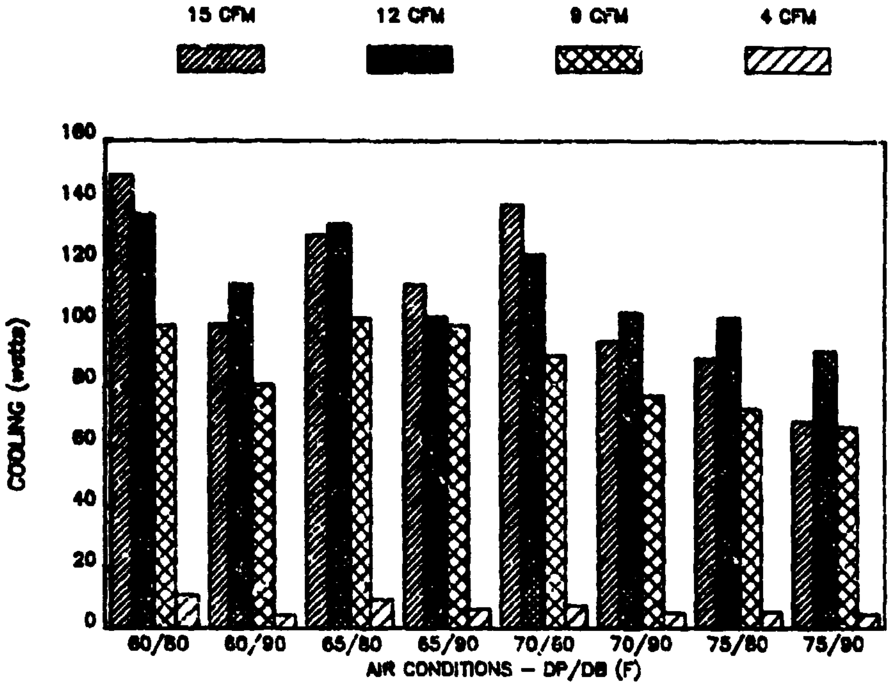

Figure 4. Measured cooling – total.

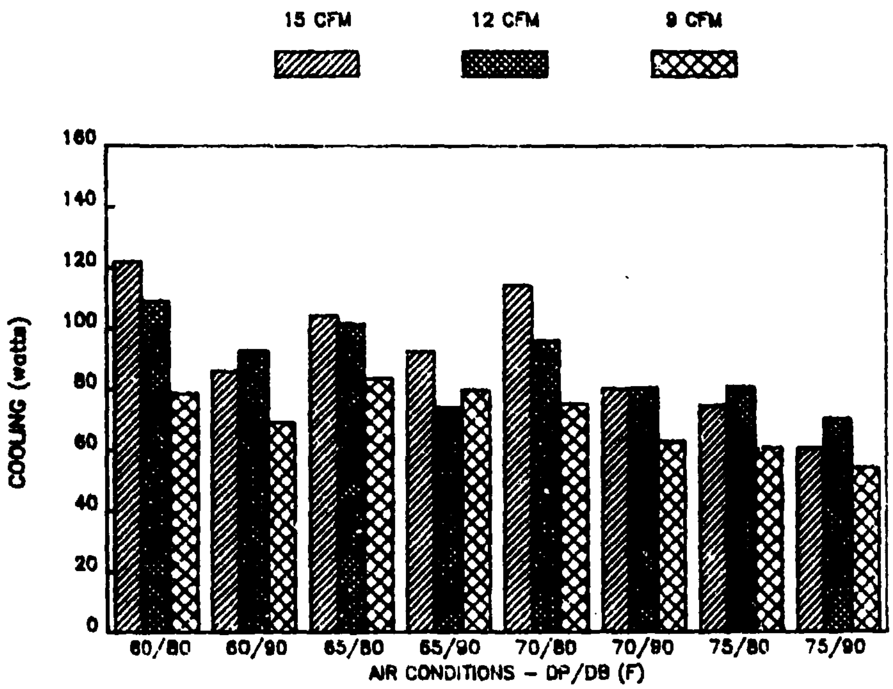

Figure 5. Measured cooling – torso.

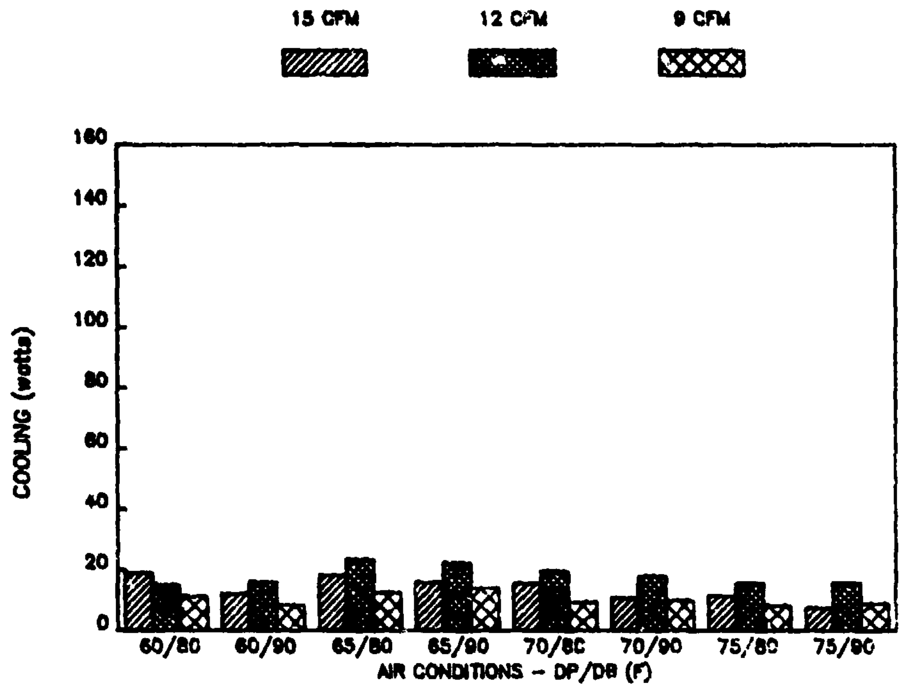

Figure 6. Measured cooling – arms.

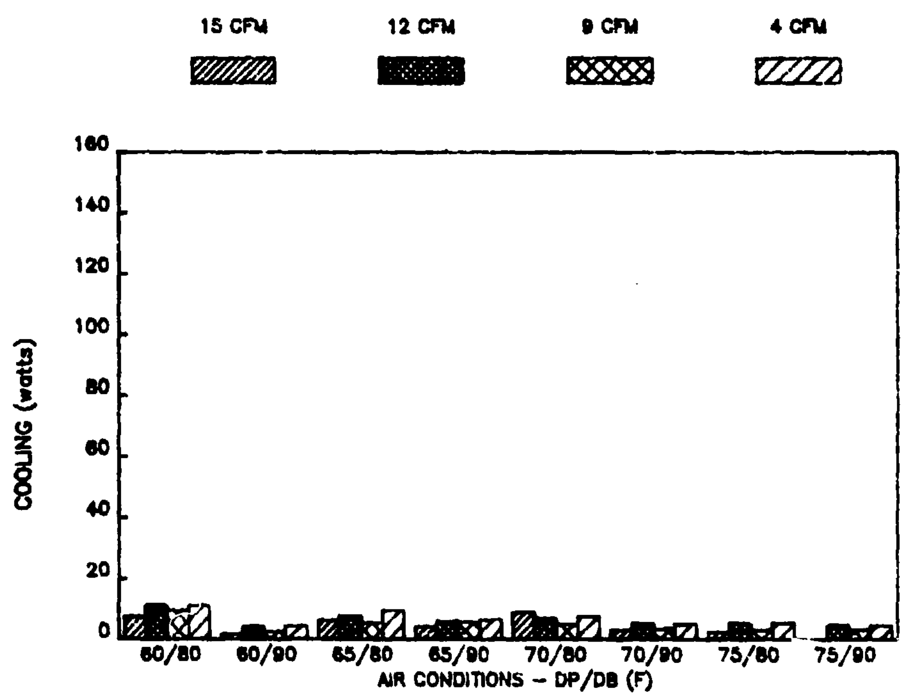

Figure 7. Measured cooling – head.

To declare two means to be significantly different, they must differ by a value at least as large as the Rp calculated for the number of intervals separating them. For example, dew points 65 and 70 are two intervals apart when their means are ranked in descending order as above. Therefore, they must differ by at least 21.5 to be declared significantly different; they do not.

From a likewise comparison of the remaining means, the only significant difference is found between a dew point of 75 and each of the other three dew points. To facilitate the determinations, those means which are NOT considered different from each other are underlined. All evaluations are at the 5% level.

A similar analysis of the interactions between the main factors indicated a significance only for the dew point/flow rate combination; also at the 5% level.

The analysis failed to find the significant differences predicted by the F values that were calculated.

The cooling levels measured represented about 35% of the theoretical maximum values. Since the air exiting through the neck holes of the vest is directed upward (above the dividing line between the torso and the head of the manikin), any cooling achieved from that air would have shown up in the head values, not in those of the torso or arms. For this reason, the calculations used to determine the actual to theoretical ratios (or % efficiency), used air flows equal to 85% of the air entering the vest and used power values equal to the sum of the torso and arms. A sample calculation is presented below.

condition: 65/90/12
maximum theoretical cooling (App. B): 34 $W \cdot cfm^{-1}$
total air flow: 12 cfm
air flow to mask: 3 cfm
fraction of vest air flow to neck: 0.15
air distributed to torso and arms: (12 - 3) x (1 - 0.15) = 7.65 cfm
measured cooling to torso and arms (Fig. B.1): 96 W
96 W / 7.65 cfm = 12.5 $W \cdot cfm^{-1}$
12.5 / 34 x 100 = 36.8%

air distributed to head: 3 + (9 x 0.15) = 4.35 cfm
measured cooling to head: 12 W
12 W / 4.35 cfm = 2.76 $W \cdot cfm^{-1}$
2.76 / 34 x 100 = 8.1%

It should be noted that for condition 29 set (75/90/15) a power level of 0 $Btu \cdot hr^{-1}$ (0 W) was measured at the right arm and head. Values in this instance were estimated from the other data.

The attempt to determine the saturation level of the air exiting the AUIB produced unreliable results that bore no resemblence to the measured cooling values. A different method needs to be devised for future studies.

DISCUSSION

The results presented above offer insight for those individuals developing microclimate cooling systems. Throughout this discussion it must be kept in mind that only one measurement was made at each set of conditions. Although steady state was achieved before a change was effected, the reported value may or may not represent the true mean of a normally distributed population of cooling values. Such a determination would require a much more extensive effort. The extra data collected may also remove the ambiguities of the statistical analysis. The assumption that the collected data do represent mean values, will however, be made for the purpose of discussion.

Based on the data, the air vest provided an average of 26% of the theoretical maximum cooling. The calculated efficiency of the air distributed over the torso alone (neglecting the air exiting at the neck and the air split off to the M43) was found to be 34%. These figures highlight the relative capabilities of torso versus head cooling.

While these percentages will probably be increased in future iterations of the cooling garment, the current design is adequate for many situations. In the case of an aviator working at 580 $Btu \cdot hr^{-1}$ (170 W) for 2 1/2 hours and receiving air at 70/80/12 (condition 10), the following calculation could be made:

$$170\ W - 123\ W = 47\ W = 160\ Btu \cdot hr^{-1} \quad \text{(rate of heat storage)}$$

$$160\ Btu \cdot hr^{-1} \times 2.5\ hr = 400\ Btu \quad \text{(heat storage for mission)}$$

$$400\ Btu\ /\ 0.85^{*}\ Btu/lbm^{-1} \cdot {}^{\circ}F^{-1}\ /\ 160\ lbm = 2.9^{\circ}F\ (1.6^{\circ}C)$$

A 1.6 C core temperature rise should prove to be acceptable.

Analysis of the data showed that the cooling achieved in the torso and arms accounted for an average of 95% of the total cooling. Where a separate breathing air supply is available, as in the case of the M43 with its dedicated blower unit, it may be more efficacious to deliver all of the conditioned air to the vest and to use the M43 blower as a facepiece supply. However, the feeling of cool air on the face and in the lungs has a psychological benefit that to date has proved unquantifiable.

The lower than expected values recorded at five of the 15 cfm flow rates may be a result of redressing the manikin before that set of runs was made (chamber scheduling made this unavoidable). However, since three of the runs do show increased levels of cooling compared to 12 cfm, this cannot be the sole explanation.

The design of the M43 facepiece, with the capability to distribute air over the head, and in conjunction with the HGU56, does allow for some cooling to take place in this area. The amount of air that gets diverted from the nosecup to the top of the head was not measured. This may be a variable worth investigating for future iterations of the mask.

The data also point out the need for a more thorough investigation of the heat transfer and fluid flow parameters governing the system. The geometry, flow patterns, and driving forces within the closed system need to be examined individually and in concert to properly recommend a second generation garment design.

* an approximation of the heat capacity, Cp, of the body

REFERENCES

1. M.M. Toner, R.E. White, and R.F. Goldman, "Thermal stress inside the XM-1 Tank during operations in an NBC environment and its potential alleviation by auxilliary cooling" USARIEM T-4/81, May 1981.

2. T.H. Tassinari and V.D. Iacono, "Microclimate controlled tank crewmen clothing for extended mission time in chemical-biological environments" NATICK/TR-85/002L, December 1984 (AD B089337L).

3. V. Iacono, T. Tassinari, M. Kupcinskas, and J. Cohen, "Performance comparison of three microclimate systems for cooling of ground vehicle crewmen in chemical protective clothing during simulated desert and tropical exposures" NATICK/TR-84/040L, July 1984 (AD B085628L).

4. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "ASHRAE Handbook - 1981 Fundamentals", Ch.5, 1981.

5. R.C. Weast, ed., "CRC Handbook of Chemistry and Physics", 63rd ed., pp.F-9,10, 1982.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-87/002 in the series of reports approved for publication.

APPENDICES

A. Environmental conditions

B. Theoretical cooling derivation

C. Listing of computer program "TABLE" used to calculate the cooling potential of air

BLANK

APPENDIX A

Environmental conditions

APPENDIX A

The average environmental conditions were:

dew point(DP) -	93.5 ± 1.4°F*	dry bulb temperature (DB) -	122.4 ± 1.0°F
	34.2 ± 0.8°C		50.2 ± 0.6°C
globe temperature(GT) -	140.4 ± 3.1°F	WBGT -	105.8 ± 1.4°F
	60.2 ± 1.7°C		41.0 ± 0.8°C

The WBGT is calculated as follows:

$$WBGT = (0.7 \times DP) + (0.1 \times DB) + (0.2 \times GT)$$

The wet bulb globe temperature, WBGT, is a parameter that attempts to relate, in one number, the combined effects of dry bulb temperature, humidity and radiation. When using this number it must be kept in mind that an infinite number of combinations of DP, DB, and GT can result in the same WBGT and that not all of the combinations present the same danger from heat stress.

* Numbers shown are mean ± standard deviation

APPENDIX B

Theoretical cooling derivation

APPENDIX B

Maximum theoretical cooling is defined here as that level of heat removal achieved when the air exiting the garment has been raised to skin temperature and saturated. Of course, this is a value that can never be quite reached. To do so would require either the residence time of the air within the garment approach infinity or the surface area available for heat exchange (the body) approach infinity. The parameter does however, describe a limit next to which the return on investment of design effort can be gauged.

The BASIC program written to tabulate maximum theoretical cooling is called TABLE (Appendix C). The heart of the program lies between lines 800 and 1110. It is here that the enthalpy levels of the inlet and exit air are calculated, based on the conditions initially entered by the user. First, the Antoine equation is applied to determine the vapor pressure (Pw) at the dew point (lines 830 and 1060). The value returned has units of mm Hg (1 mm Hg = 133.3 $N \cdot m^{-2}$). The humidity ratio (W) is found next (lines 840 and 1070). It is the ratio of the mass of water to the mass of air. The term is dimensionless. The enthalpies are then found by a correlation given in Ref. 4. The terms of the equation represent the specific enthalpies of dry air and water vapor (lines 850 and 1080). The units used are $Btu \cdot lbm^{-1}$ (1 $Btu \cdot lbm^{-1}$ = 2,321 $J \cdot kg^{-1}$).

The density of the air is determined based on the dry bulb temperature of the inlet air. The equation (line 1090), though a relation for the dry air density (Ref. 5), differs by less than 1% from the value for moist air in the worst case. The density is given in units of $lbm \cdot ft^{-3}$ (1 $lbm \cdot ft^{-3}$ = 0.013 $kg \cdot m^{-3}$). The last two lines of the section (1100 and 1120) calculate the delta enthalpy and convert the output to $W \cdot ft^{-3}$.

Table C-1 is the output of TABLE when run with the following user input - exit air conditions of 95°F dry bulb temperature and 95°F dew point, inlet air dew point range of 60 to 80°F, and inlet air dry bulb temperature range of 60 to 100°F.

The measured cooling values for the torso and both arms were combined to allow for calculation of the efficiency of the air distributed to the chest and the back (Fig. B-1). The air flow rate used was the total flow minus 3 cfm (which is split off to the mask) multiplied by 0.85 to account for the air exiting the neck holes. Only this quantity of air and only the power levels of the torso and arms were used because this is the region where 95% of the cooling took place (by comparison of Figs. 4 and 7) and is also the area where improvements in design can be most readily be effected.

Following the procedure outlined in the sample calculation in the RESULTS section and averaging the values for 15, 12, and 9 cfm for each DP/DB pair, the ratios of measured-to-maximum cooling values are as follows:

DP/DB -	60/80	65/80	70/80	75/80	60/90	65/90	70/90	75/90
ratio -	0.34	0.31	0.36	0.35	0.38	0.35	0.30	0.33

average efficiency - 34%

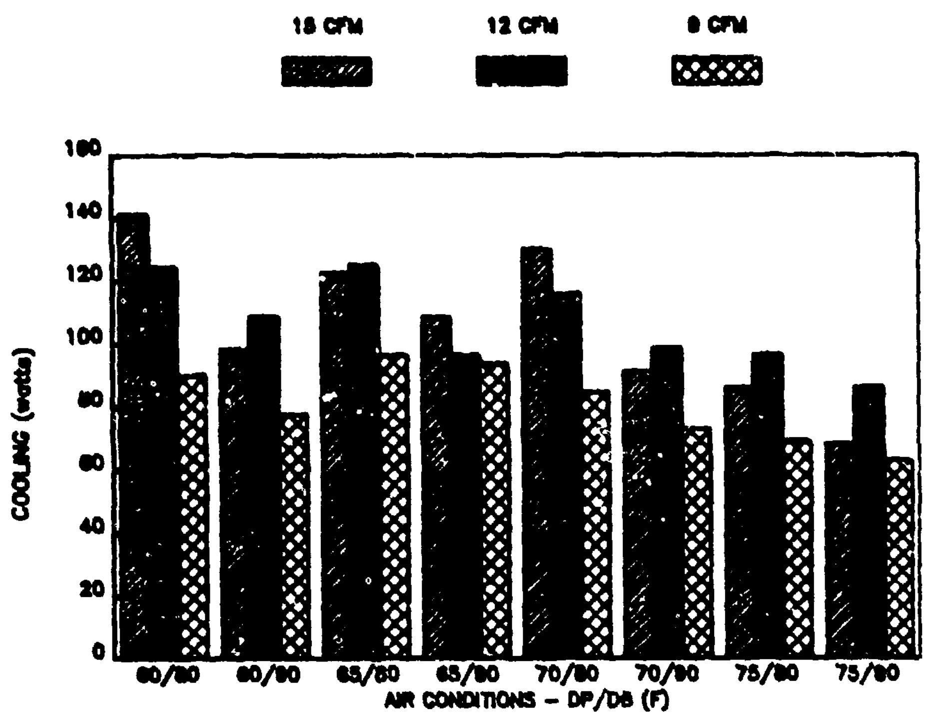

Figure B-1. Measured cooling - torso + arms.

BLANK

APPENDIX C

Listing of the computer program TABLE used to calculate the cooling potential of air

```
10!!! this program is called TABLE
20!!!
30!!! the first section of the program instructs the user regarding
40!!! the data required for input
50!!!
60    PRINT "THIS PROGRAM WILL PRINT OUT A TABLE OF VALUES OF THE COOLING POTENT
IAL OF AIR."
70    PRINT " "
80    PRINT "YOU WILL BE ASKED TO INPUT THE EXIT AIR CONDITIONS (DEW POINT AND D
RY BULB TEMP-ERATURE) AND THE RANGE OF"
90    PRINT "INLET AIR CONDITIONS YOU ARE INTERESTED IN."
100   PRINT " "
110   PRINT "VALUES ENTERED IN THIS PROGRAM MUST BE IN FAHRENHEIT DEGREES."
120   WAIT 10
130   PRINT "TYPE IN THE DRY BULB TEMPERATURE OF THE EXIT AIR AND PRESS ENTER"
140   INPUT Db2
150   PRINT "TYPE IN THE DEW POINT OF THE EXIT AIR AND PRESS ENTER"
160   INPUT Dp2
170   FOR Q=1 TO 5
180       PRINT " "
190   NEXT Q
200   PRINT "CHOOSE THE RANGE (1 OR 2) OF THE INLET AIR DEW POINTS YOU ARE INTER
ESTED IN -   1) 60 - 80 ; 2) 80 - 100 THEN PRESS ENTER"
210   INPUT E
220   PRINT " "
230   PRINT "CHOOSE THE RANGE (1 OR 2) OF THE INLET AIR DRY BULB TEMPERATURES YO
U ARE INTER-ESTED IN -  1) 60 - 100 ; 2) 60 - 120 THEN PRESS ENTER"
240   INPUT F
250   PRINT " "
260   PRINT " "
270   PRINT " "
280   PRINT " "
290   PRINT "THIS IS A TABLE OF VALUES OF THE COOLING POTENTIAL OF AIR.  THE HOR
IZONTAL AXIS IS THE DEW POINT OF THE INLET AIR.  THE VERTICAL AXIS IS THE DRY"
300 PRINT "BULB TEMPERATURE OF THE INLET AIR.  BOTH TEMPERATURES ARE IN DEGREES
FAHRENHEIT.THE VALUES IN THE TABLE REPRESENT THE COOLING POTENTIAL OF THE AIR."
310   PRINT "THE UNITS ARE WATTS PER CUBIC FOOT PER MINUTE (W/ft^3/min)."
320   PRINT " "
330   PRINT "(TO CONVERT TEMPERATURES TO DEGREES CELSIUS, SUBTRACT 32 AND DIVIDE
 BY 1.8)"
340   PRINT "(TO CONVERT POTENTIALS TO W/m^3/min, MULTIPLY THE VALUES BY 0.028)"
350   PRINT " "
360   PRINT "THE VALUES REPRESENT THE DIFFERENCE IN ENTHALPY BETWEEN THE AIR ENT
ERING THE    GARMENT AND THE AIR EXITING THE GARMENT.  MAXIMUM COOLING IS"
370   PRINT "THEORETICALLY ACHIEVED WHEN THE OUTLET AIR IS SATURATED AND AT A TE
MPERATURE    EQUAL TO THAT OF THE SKIN."
380   PRINT "FOR THESE CALCULATIONS, EXIT TEMPERATURE WAS TAKEN TO BE";Db2;"DEGR
EES FAHRENHEIT. THE DEW POINT OF THE EXIT AIR IS";Dp2;"DEGREES FAHRENHEIT."
390   PRINT " "
400   PRINT "FOR CONVIENIENCE, ASTERIKS HAVE BEEN PLACED AT TEN DEGREE INTERVALS
."
410   WAIT 60
420   PRINT "  "
430   PRINT "  "
440!!!
450!!!
460   IF E=1 THEN                  !
470       Dp=59                    !     determine the starting
480   ELSE                         !     dew point and initialize Dp
490       Dp=79                    !
500   END IF                       !
```

```
510!!!
520!!!
530 PRINT USING "35X,22A,/";"DEW POINT (DEGREES F)"        ! label for columns
540  PRINT USING "14X,#"                       !
550  R=I MOD 10                                !
560  IF R=1 OR R=2 THEN GOTO 730               !
570  DIM Y(62,22)                              !
580  Y(1,1)=0                                  !
590  FOR J=1 TO 22 STEP 1                      !
600      IF J=1 THEN GOTO 750                  !
610      Y(1,J)=Dp+1                           !
620      Dp=Y(1,J)                             !    print out top row
630      IF J=2 THEN GOTO 730                  !
640      IF J=11 THEN GOTO 730                 !    of table
650      IF J=12 THEN GOTO 730                 !
660      IF J=21 THEN GOTO 730                 !    i.e. column headings
670      IF Dp<100 THEN GOTO 700               !
680      PRINT USING "3D,#";Y(1,J)             !
690      GOTO 740                              !
700      IF J=22 THEN GOTO 730                 !
710      PRINT USING "DD,X,#";Y(1,J)           !
720      IF J>1 THEN GOTO 760                  !
730      PRINT USING "DD,A,#";Y(1,J),"*"       !
740      GOTO 760                              !
750      PRINT USING "XX,A,#";"*"              !
760   NEXT J                                   !
770   PRINT "                 *************************************************
*************"                                  !
780!!!
790!!!
800   A=8.10765                                         !
810   B=1750.286                                        ! constants for Antoine equation
820   C=235.0                                           !
830   Pw2=10^(A-(B/(C+((Dp2-32)/1.8))))                   ! Antoine equation
840   W2=.62198*(Pw2/(760-Pw2))                           ! humidity ratio
850   H2=(.240*Db2)+(W2*(1061+(.444*Db2)))                ! exit air enthalpy
860 !!
870 !!
880   IF F=1 THEN G=42      !  set the number
890   IF F=2 THEN G=62      !     of rows
900   Db=59         ! initialize dry bulb temperature
910 !!
920 !!  start loop for rows
930 !!
940   FOR I=2 TO G STEP 1
950       PRINT USING "13X,#"
960       Db=Db+1
970       IF E=1 THEN       !
980          Dp=59          !   re-determine the starting
990       ELSE              !
1000         Dp=79          !        dew point
1010      END IF            !
1020      FOR J=2 TO 22 STEP 1                          ! start loop for columns
1030         Dp=Dp+1
1040         T=(Db-32)/1.8
1050!!
1060         Pw=10^(A-(B/(C+((Dp-32)/1.8))))                ! Antoine equation
1070         W=.62198*(Pw/(760-Pw))                         ! humidity ratio
1080         H1=(.240*Db)+(W*(1061+(.444*Db)))              ! inlet air enthalpy
1090         Rho=(1.2929*(273.13/(T+273.13)))*.062305       ! inlet air density
1100         Delh=H2-H1                                ! delta enthalpy
```

```
1110      Wcfm=Delh*Rho*.2931*60          ! theoretical maximun cooling
1120!!
1130!!
1140!!  remainder of the program is output formatting
1150        IF J>2 THEN GOTO 1210
1160        Y(I,1)=Db
1170        IF I<42 THEN GOTO 1200
1180        PRINT USING "3D,A,#";Y(I,1),"*"
1190        GOTO 1210
1200        PRINT USING "DD,AA,#";Y(I,1),"**"
1210        Y(I,J)=Wcfm
1220        IF Y(I,J)>0 THEN GOTO 1240
1230        Y(I,J)=ABS(Y(I,J))
1240        IF J=2 THEN GOTO 1300
1250        R=I MOD 10
1260        IF R=1 OR R=2 THEN GOTO 1300
1270        IF Dp>Db THEN GOTO 1350
1280        PRINT USING "DD,X,#";Y(I,J)
1290        IF J>=2 THEN GOTO 1360
1300        IF Dp>Db THEN GOTO 1330
1310        PRINT USING "DD,A,#";Y(I,J),"*"
1320        IF J>=2 THEN GOTO 1360
1330        PRINT USING "XX,A,#";"*"
1340        IF J>=2 THEN GOTO 1360
1350        PRINT USING "3X,#"
1360      NEXT J
1370      IF I=2 THEN GOTO 1450
1380      R=I MOD 10
1390      IF R=1 OR R=2 THEN GOTO 1450
1400      IF I=16 THEN GOTO 1470
1410      IF I=18 THEN GOTO 1490
1420      IF I=20 THEN GOTO 1510
1430      PRINT USING "15X,2A,2X,A,26X,A,2X,A,26X,A,2X,A";"**","*","*","*","*","*
"
1440      IF I>2 THEN GOTO 1520
1450      PRINT "                *****************************************************
****************"
1460      IF I>1 THEN GOTO 1520
1470      PRINT USING "4X,3A,8X,2A,2X,A,26X,A,2X,A,26X,A,2X,A";"DRY","**","*","*"
,"*","*","*"
1480      IF I>1 THEN GOTO 1520
1490      PRINT USING "4X,4A,7X,2A,2X,A,26X,A,2X,A,26X,A,2X,A";"BULB","**","*","*
","*","*","*"
1500      IF I>1 THEN GOTO 1520
1510      PRINT USING "X,11A,3X,2A,2X,A,26X,A,2X,A,26X,A,2X,A";"(DEGREES F)","**"
,"*","*","*","*","*"
1520  NEXT I
1530  IF E=2 THEN
1540      PRINT " "
1550      PRINT "NOTE: values below and to the right of a 0 are NEGATIVE and indi
cate a NET HEAT-ING effect"
1560  ELSE
1570      GOTO 1590
1580  END IF
1590  END
```

Table C-1. Sample output of TABLE program.

THIS PROGRAM WILL PRINT OUT A TABLE OF VALUES OF THE COOLING POTENTIAL OF AIR.

YOU WILL BE ASKED TO INPUT THE EXIT AIR CONDITIONS (DEW POINT AND DRY BULB TEMP-ERATURE) AND THE RANGE OF
INLET AIR CONDITIONS YOU ARE INTERESTED IN.

VALUES ENTERED IN THIS PROGRAM MUST BE IN FAHRENHEIT DEGREES.
TYPE IN THE DRY BULB TEMPERATURE OF THE EXIT AIR AND PRESS ENTER
TYPE IN THE DEW POINT OF THE EXIT AIR AND PRESS ENTER

CHOOSE THE RANGE (1 OR 2) OF THE INLET AIR DEW POINTS YOU ARE INTERESTED IN -
1) 60 - 80 ; 2) 80 - 100 THEN PRESS ENTER

CHOOSE THE RANGE (1 OR 2) OF THE INLET AIR DRY BULB TEMPERATURES YOU ARE INTER-E
STED IN - 1) 60 - 100 ; 2) 60 - 120 THEN PRESS ENTER

THIS IS A TABLE OF VALUES OF THE COOLING POTENTIAL OF AIR. THE HORIZONTAL AXIS
IS THE DEW POINT OF THE INLET AIR. THE VERTICAL AXIS IS THE DRY
BULB TEMPERATURE OF THE INLET AIR. BOTH TEMPERATURES ARE IN DEGREES FAHRENHEIT.
THE VALUES IN THE TABLE REPRESENT THE COOLING POTENTIAL OF THE AIR.
THE UNITS ARE WATTS PER CUBIC FOOT PER MINUTE (W/ft^3/min).

(TO CONVERT TEMPERATURES TO DEGREES CELSIUS, SUBTRACT 32 AND DIVIDE BY 1.8)
(TO CONVERT POTENTIALS TO W/m^3/min, MULTIPLY THE VALUES BY 0.028)

THE VALUES REPRESENT THE DIFFERENCE IN ENTHALPY BETWEEN THE AIR ENTERING THE
GARMENT AND THE AIR EXITING THE GARMENT. MAXIMUM COOLING IS
THEORETICALLY ACHIEVED WHEN THE OUTLET AIR IS SATURATED AND AT A TEMPERATURE
EQUAL TO THAT OF THE SKIN.
FOR THESE CALCULATIONS, EXIT TEMPERATURE WAS TAKEN TO BE 95 DEGREES FAHRENHEIT.
THE DEW POINT OF THE EXIT AIR IS 95 DEGREES FAHRENHEIT.

FOR CONVIENIENCE, ASTERIKS HAVE BEEN PLACED AT TEN DEGREE INTERVALS.

```
                         DEW POINT (DEGREES F)

   *60*61 62 63 64 65 66 67 68 69*70*71 72 73 74 75 76 77 78 79*80*
  ******************************************************************
60**49*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
********************************************************************
61**49*48
  **  *                            *  *                          *  *
62**48*48 47
  **  *                            *  *                          *  *
63**48*47 47 46
  **  *                            *  *                          *  *
64**48*47 46 46 45
  **  *                            *  *                          *  *
65**47*47 46 45 45 44
  **  *                            *  *                          *  *
66**47*46 46 45 44 44 43
  **  *                            *  *                          *  *
67**46*46 45 44 44 43 42 42
  **  *                            *  *                          *  *
68**46*45 45 44 43 43 42 41 41
```

```
              69**45*45*44*44*43*42*42*41*40*39*  *  *  *  *  *  *  *  *  *  *  *
              ********************************************************************
              70**45*44*44*43*43*42*41*41*40*39*38*  *  *  *  *  *  *  *  *  *  *
              ********************************************************************
              71**45*44 43 43 42 42 41 40 39 39 38 37
                **  *                          *  *                          *  *
              72**44*44 43 42 42 41 40 40 39 38 37 37 36
                **  *                          *  *                          *  *
              73**44*43 43 42 41 41 40 39 39 38 37 36 35 35
                **  *                          *  *                          *  *
              74**43*43 42 42 41 40 40 39 38 37 37 36 35 34 33
   DRY          **  *                          *  *                          *  *
              75**43*42 42 41 41 40 39 39 38 37 36 36 35 34 33 32
                **  *                          *  *                          *  *
              76**43*42 41 41 40 40 39 38 37 37 36 35 34 33 33 32 31
   BULB         **  *                          *  *                          *  *
              77**42*42 41 40 40 39 38 38 37 36 36 35 34 33 32 31 30 29
                **  *                          *  *                          *  *
              78**42*41 41 40 39 39 38 37 37 36 35 34 34 33 32 31 30 29 28
(DEGREES F)     **  *                          *  *                          *  *
              79**41*41*40*40*39*38*38*37*36*36*35*34*33*32*31*31*30*29*28*27*  *
              ********************************************************************
              80**41*40*40*39*39*38*37*37*36*35*34*34*33*32*31*30*29*28*27*26*25*
              ********************************************************************
              81**41*40 40 39 38 38 37 36 36 35 34 33 32 32 31 30 29 26 27 26 25
                **  *                          *  *                          *  *
              82**40*40 39 39 38 37 37 36 35 34 34 33 32 31 30 29 28 28 27 26 24
                **  *                          *  *                          *  *
              83**40*39 39 38 37 37 36 35 35 34 33 32 32 31 30 29 28 27 26 25 24
                **  *                          *  *                          *  *
              84**40*39 38 38 37 36 36 35 34 34 33 32 31 30 30 29 28 27 26 25 24
                **  *                          *  *                          *  *
              85**39*39 38 37 37 36 35 35 34 33 32 32 31 30 29 28 27 26 25 24 23
                **  *                          *  *                          *  *
              86**39*38 38 37 36 36 35 34 34 33 32 31 31 30 29 28 27 26 25 24 23
                **  *                          *  *                          *  *
              87**38*38 37 37 36 35 35 34 33 33 32 31 30 29 28 28 27 26 25 24 23
                **  *                          *  *                          *  *
              88**38*37 37 36 36 35 34 34 33 32 31 31 30 29 28 27 26 25 24 23 22
                **  *                          *  *                          *  *
              89**38*37*36*36*35*35*34*33*32*32*31*30*29*29*28*27*26*25*24*23*22*
              ********************************************************************
              90**37*37*36*35*35*34*34*33*32*31*31*30*29*28*27*26*26*25*24*23*22*
              ********************************************************************
              91**37*36 36 35 34 34 33 32 32 31 30 29 29 28 27 26 25 24 23 22 21
                **  *                          *  *                          *  *
              92**36*36 35 35 34 33 33 32 31 31 30 29 28 27 27 26 25 24 23 22 21
                **  *                          *  *                          *  *
              93**36*36 35 34 34 33 32 32 31 30 30 29 28 27 26 25 24 24 23 22 21
                **  *                          *  *                          *  *
              94**36*35 35 34 33 33 32 31 31 30 29 28 28 27 26 25 24 23 22 21 20
                **  *                          *  *                          *  *
              95**35*35 34 34 33 32 32 31 30 30 29 28 27 26 26 25 24 23 22 21 20
                **  *                          *  *                          *  *
              96**35*34 34 33 33 32 31 31 30 29 28 28 27 26 25 24 23 22 22 21 19
                **  *                          *  *                          *  *
              97**35*34 33 33 32 32 31 30 30 29 28 27 27 26 25 24 23 22 21 20 19
                **  *                          *  *                          *  *
              98**34*34 33 33 32 31 31 30 29 28 28 27 26 25 24 24 23 22 21 20 19
                **  *                          *  *                          *  *
              99**34*33*33*32*32*31*30*30*29*28*27*27*26*25*24*23*22*21*20*19*18*
              ********************************************************************
              100*34*33*32*32*31*31*30*29*28*28*27*26*25*25*24*23*22*21*20*19*18*
              ********************************************************************
```